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EFFECT OF FUEL DISTRIBUTION AND FLAME STABILIZATION TECHNIQUES ON COMBUSTION STABILITY LIMITS FOR SWIRL-CAN COMBUSTOR MODULES BURNING ASTM-A1 FUEL

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • FEBRUARY 1971

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-2185		

4. Title and Subtitle EFFECT OF FUEL DISTRIBUTION AND FLAME STABILIZATION TECHNIQUES ON COMBUSTION STABILITY LIMITS FOR SWIRL-CAN COMBUSTOR MODULES BURNING ASTM-A1 FUEL

5. Report Date
February 1971

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.
E-5968

9. Performing Organization Name and Address
Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio 44135

10. Work Unit No.
720-03

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A series of 10 single swirl-can combustor modules were tested with 40 percent area blockage in a 3.25-in. (8.26-cm) diameter duct in 600° F (589 K) air streams at reference velocities of 75 to 600 ft/sec (23 to 183 m/sec) and a pressure of 1 atm. Combustion stability-limit (blowout) data were obtained for each module consisting of a fuel distributor, an air swirler, and a flame stabilizer. The ratio of rich-to-lean combustion stability limits was decreased when the uniformity of fuel distribution was improved for reference velocities up to 400 ft/sec (122 m/sec). Optimum performance of conical flame stabilizers was obtained at a cone half-angle of approximately 15° to 20°.

17. Key Words (Suggested by Author(s))
Swirl-can combustor modules
Combustion stability limits
Conical flame stabilizers

18. Distribution Statement
Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	19	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

A study was made of the effect of fuel distribution and flame stabilization techniques on combustion stability limits (blowout conditions) for a series of 10 different swirl-can combustor modules. ASTM-A1 fuel was burned in the modules designed to give approximately 40 percent blocked area in a 3.25-inch (8.26-cm) diameter duct with 600° F (589 K) air at reference velocities of 75 to 600 feet per second (23 to 183 m/sec) and a pressure of 1 atmosphere. Also, the modules were tested at cold-flow conditions in a 6-inch (15.25-cm) diameter Lucite duct. Water instead of fuel was used in these tests to observe the liquid distribution and spray patterns produced by the various fuel distribution methods. Photographs were taken at several water-air ratios and reference velocities.

Improving the uniformity of fuel distribution tended to decrease both the lean and rich combustion stability limits and to decrease combustor performance based on the ratio of rich-to-lean combustion stability limits for reference velocities below 400 feet per second (122 m/sec). Also, blowout tests showed that the optimum performance of conical flame stabilizers was obtained at a cone half-angle of 15° to 20°. Changing from cone-type to flat-plate flame stabilizers did not improve performance based on the ratio of rich-to-lean combustion stability limits.

INTRODUCTION

The development of turbojet combustors for advanced aircraft designs requires knowledge of rapid and efficient methods of burning fuels at high heat-release rates per unit combustor volume. This is difficult to achieve while maintaining a low pressure loss in the combustor, a high combustion efficiency, a satisfactory combustor-exit temperature distribution, and a wide range of combustion stability limits.

One approach to achieve high heat-release rates per unit combustor volume for annular turbojet combustors has been that of developing swirl-can combustor modules. In reference 1, good performance was obtained for single swirl-can combustor modules tested with ASTM-A1 fuel, and effects of combustor design on performance were investigated. In reference 2 a 48-module swirl-can combustor array showed good performance when it was tested at high temperatures using ASTM-A1 fuel. Also, good results were obtained for a 48-module swirl-can array when flat plates were used as flame stabilizers (ref. 3).

The following advantages have been shown for swirl-can combustor modules: improved durability was obtained by eliminating the diluent air entry-ports which present stress problems in conventional combustor liners, combustor-exit temperature profiles were adjusted by controlling fuel flow to individual combustor modules, nozzle fouling due to high temperatures was avoided by the use of low-pressure fuel injectors with relatively large fuel passages within the combustor and control orifices located outside of the combustor, and smoke formation was reduced by premixing of fuel and air.

Two of the problems encountered with swirl-can combustor modules are the distribution of the fuel and the stabilization of the flame. For example, at low fuel flow rates the fuel injection velocity is of the order of 1 foot per second (0.305 m/sec). Thus, the fuel tends to puddle at the bottom of the module and very poor mixing of fuel and air occurs. This makes altitude relight difficult. The effect of the cone angle of the flame stabilizer on module performance has been studied for natural gas fuel (ref. 4), but this effect has not been studied for modules using liquid fuels.

The purpose of this investigation was to determine the effect of fuel distribution techniques and flame-stabilizer shapes on the performance of swirl-can combustor modules. A single swirl-can combustor module similar to that used in reference 1 was tested and used as a standard of comparison for a series of swirl-can modules having various modifications in fuel-distributor and flame-stabilizer design. Photographs of water sprays produced by the injectors were obtained in cold-flow tests to determine liquid distribution patterns. Combustion stability-limit (blowout) data were obtained by burning ASTM-A1 fuel in air streams preheated to 600° F (589 K). Also, the appearance of the flame was observed at various operating conditions.

APPARATUS AND PROCEDURE

Swirl-can combustor modules were tested in the 3.25-inch (8.26-cm) diameter test section shown in figure 1. ASTM-A1 fuel was burned in the test modules with airflow provided by the laboratory supply system. Airflow rates were measured with a square-edged orifice, installed according to ASME specifications, and fuel flow rates were measured with a turbine-type flowmeter. A direct-fired (vitiating) preheater burning natural gas fuel was used to preheat the airstream to 600° F (589 K). Downstream of the preheater a J47 combustor can and several sets of screens were used to smooth out the temperature profile of the gas stream. The inlet-air temperature to the test module was measured with an iron-constantan thermocouple located directly upstream of the test module. A viewing window was located directly downstream of the test section.

As shown in figure 1, the test module was centered in the test section. The percent of blocked area due to the test module (40 percent) was typical of that used in turbojet modular combustors designed for low pressure loss and short burning lengths.

Combustion stability-limit data were obtained by setting the airflow rate at a given reference velocity, and slowly increasing (or decreasing) the fuel flow rate until a rich (or lean) blowout occurred. A reference velocity range of 75 to 600 feet per second (23 to 183 m/sec) was used in these tests.

Fuel-air ratios at the limiting fuel flow conditions were calculated from the respective weight flow rates of fuel and air. The calculation of the reference velocity for the test module was based on the cross-sectional area of the test section and the inlet gas-stream temperature of 600° F (589 K) and static pressure of 1 atmosphere.

Swirl-can combustor modules were also tested under cold-flow conditions in the 6-inch (15.25-cm) diameter Lucite test section shown in figure 2. After the airflow was set at the desired reference velocity, the water flow rate was set to give the desired equivalent fuel-air ratio used in the combustion tests. Photographs of the water sprays were then obtained with a camera and a single, short-duration, high-intensity flash.

A drawing of the swirl-can combustor module used as a standard for comparison is shown in figure 3. Liquid was injected tangentially into the upstream portion of the module and was broken up into a spray as the liquid was forced through the swirler by its own momentum and that of the air stream. The other nine swirl-can combustor modules which were tested in this investigation are described in table I.

RESULTS AND DISCUSSION

The series of six photographs in figure 4 shows the spray patterns produced by injecting water into the swirl-can combustor module used as a standard for comparison in these tests. Water flow rates of 24.4 to 381 pounds per hour (11.1 to 173 kg/hr) were used to simulate fuel-air ratios of 0.004, 0.015, and 0.025. Airstream velocities of 100 and 250 feet per second (30.5 and 76 m/sec) were used for these tests at atmospheric pressure and ambient air temperature. Figure 4 shows that the liquid was not uniformly distributed inside the module. Instead, most of the water was sprayed from the upper right portion of the module at all of the flow conditions.

Effect of Fuel Distribution Methods on Combustion Stability Limits

In order to study the effect of fuel distribution on combustion stability limits, four swirl-can combustor modules were tested. Each model had a different method of fuel distribution. Figure 5(a) shows a plot of lean and rich combustion stability-limit data for the swirl-can combustor module used as a standard for comparison. The data cover a range of reference velocities of 75 to 600 feet per second (23 to 183 m/sec). Similar plots of data are shown in figures 5(b) to (d) for the three remaining swirl-can modules. Figure 6 shows a comparison of the stability performance of the four modules.

For the module (model 1) shown in figure 5(b), fuel was injected from a distributor ring (with eight 0.038-cm-diam orifices) in order to uniformly distribute the fuel across the swirler blades. The water-spray photograph in this figure shows that liquid was fairly well distributed over both the upper and lower portions of the module. This gave some improvement over the spray pattern shown in figure 4 for the swirl-can combustor module in which liquid was injected tangentially along the fuel distributor wall.

Fuel was injected into the airflow inside the module as a thin cylindrical sheet in the case of the module (model 2) shown in figure 5(c). The water-spray photograph shown in this figure indicates that liquid distribution was approximately as good as that obtained with the model 1 module. The module (model 3) shown in figure 5(d) had fuel injected as a thin film over the inside wall, and again the water-spray pictures showed that the liquid was fairly well distributed as in the case of models 1 and 2.

A comparison of the combustion stability limits obtained for the four modules, as shown in figure 6, indicates that improving the distribution of fuel tended to shift both the lean and rich combustion stability limits toward lower fuel-air ratios. Also, the swirl-can combustor module used as a standard for comparison appeared to have the widest range of combustion stability limits (i.e., difference between rich and lean limits), particularly at the lower reference velocities.

Another comparison of combustor performance was made in which the ratio of rich-to-lean combustion stability limits was plotted against the reference velocity, as shown in figure 7. A large value of the ratio of rich-to-lean combustion stability limits usually indicates that a combustor can be expected to maintain a stable flame at severe operating conditions such as low pressures or high velocities. Figure 7 shows that for reference velocities below 400 feet per second (122 m/sec) the swirl-can combustor module used as a standard for comparison gave the best performance based on the ratio of rich-to-lean combustion stability limits. On the basis of this ratio, the model 1 module showed the best performance for reference velocities above 400 feet per second (122 m/sec).

Effect of Flame-Stabilizer Shape on Combustion Stability-Limits

The cone half-angle and the length of the flame stabilizer were varied, and two flat-plate flame stabilizers were also tested in the final portion of this study. The same blocked area (40 percent) was maintained for all these tests. Each module used the same fuel distributor as that of the model 1 module, which had a flame stabilizer with a cone half-angle of 7°. The combustor modules (models 4 to 7) having cone half-angles of 15°, 30°, 45°, and 60°, respectively, are shown in figure 8. Combustion stability limits for these four modules (models 4 to 7) and the model 1 module are shown in figure 9. From the blowout data in figure 9, values of the ratio of rich-to-lean combustion stability limits were calculated and plotted against reference velocities, as shown in figure 10. A crossplot of figure 10 is given in figure 11, which shows the effect of the cone half-angle of the flame stabilizer on the performance of the module. Figure 11 shows that the optimum cone half-angle is 15° to 20°.

Combustion stability-limit data for flat-plate flame stabilizers are shown in figure 12. The fuel distributor was the same type as that used for the model 1 module. A comparison of performance based on the ratio of rich-to-lean combustion stability limits is shown in figure 13 for the flat-plate flame stabilizers, the model 4 module, and the swirl-can module used as a standard for comparison. This figure shows that the flat-plate flame stabilizers did not give as wide a range of combustion stability limits as those obtained with the module used as a standard for comparison. The best results were obtained with the model 4 module consisting of a fuel distributor with eight (0.038-cm-diam) orifices and a flame stabilizer with a 15° cone half-angle.

SUMMARY OF RESULTS

Combustion stability limits (blowout conditions) were obtained for a series of 10 different swirl-can combustor modules in which ASTM-A1 fuel was burned in a 3.25-inch (8.26-cm) diameter duct with 600° F (589 K) air at reference velocities of 75 to 600 feet per second (23 to 183 m/sec) and a pressure of 1 atmosphere. A comparison of results showed that

1. Improving the uniformity of fuel distribution tended to decrease both the lean and rich combustion stability limits and to decrease the ratio of rich-to-lean combustion stability limits, for reference velocities below 400 feet per second (122 m/sec).

2. Conical flame stabilizers gave an optimum ratio of rich-to-lean combustion stability limits at a cone half-angle of 15° to 20°.

3. Changing from cone-type to flat-plate flame stabilizers did not improve performance based on the ratio of rich-to-lean combustion stability limits.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 27, 1970,
720-03.

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3. Niedzwiecki, Richard W.: Preliminary Tests of a Simplified Modular Turbojet Combustor. NASA TN D-5688, 1970.
4. Marchionna, Nicholas R.: Stability Limits and Efficiency of Swirl-Can Combustor Modules Burning Natural Gas Fuel. NASA TN D-5733, 1970.

TABLE I. - DESCRIPTION OF SWIRL-CAN COMBUSTOR MODULES:

MODELS 1 TO 9

Model	Fuel distributor	Flame stabilizer
1	Hollow ring with eight 0.038-cm diameter orifices injecting fuel downstream	Conical with a 7^{o} cone half-angle
2	Hollow cone with a 0.038-cm-wide slit injecting fuel out into the airstream	Conical with a 7^{o} cone half-angle
3	Hollow ring with a 0.038-cm-wide slit injecting fuel along the wall	Conical with a 7^{o} cone half-angle
4	Same as model 1	Conical with a 15^{o} cone half-angle
5	Same as model 1	Conical with a 30^{o} cone half-angle
6	Same as model 1	Conical with a 45^{o} cone half-angle
7	Same as model 1	Conical with a 60^{o} cone half-angle
8	Same as model 1	Flat plate with a hexagon shape
9	Same as model 1	Flat plate with a pentagon shape

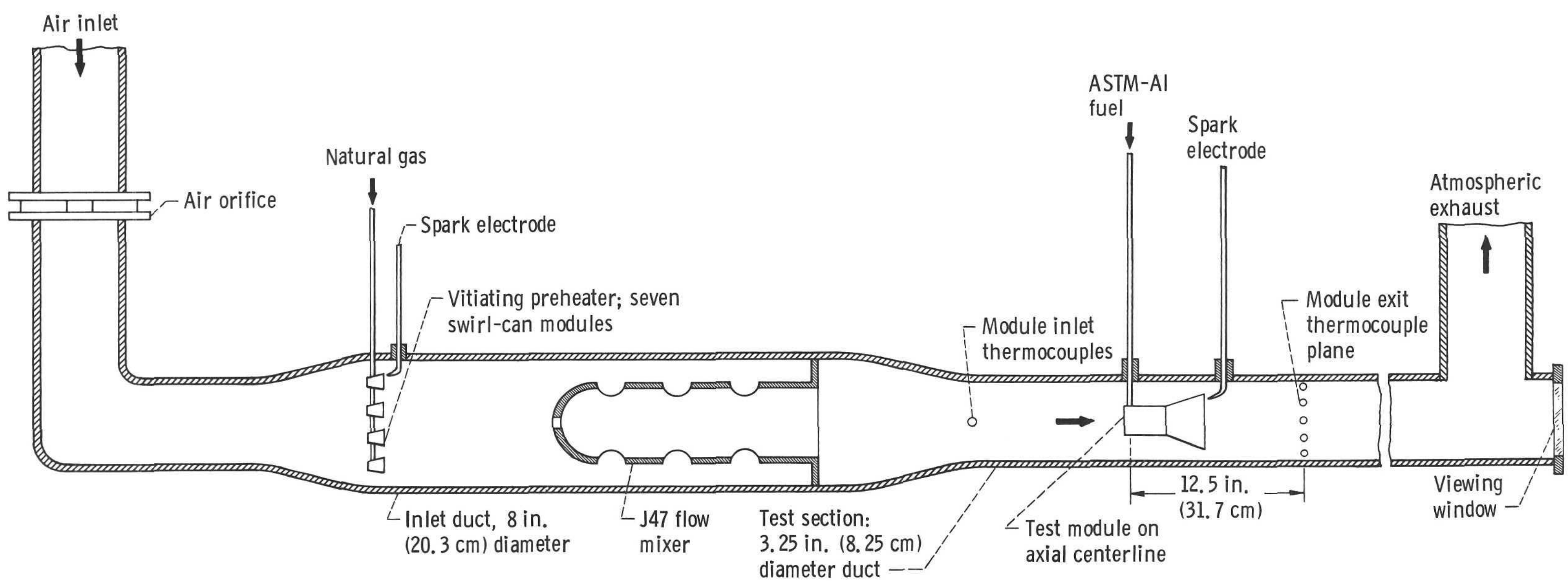


Figure 1. - Combustion test facility.

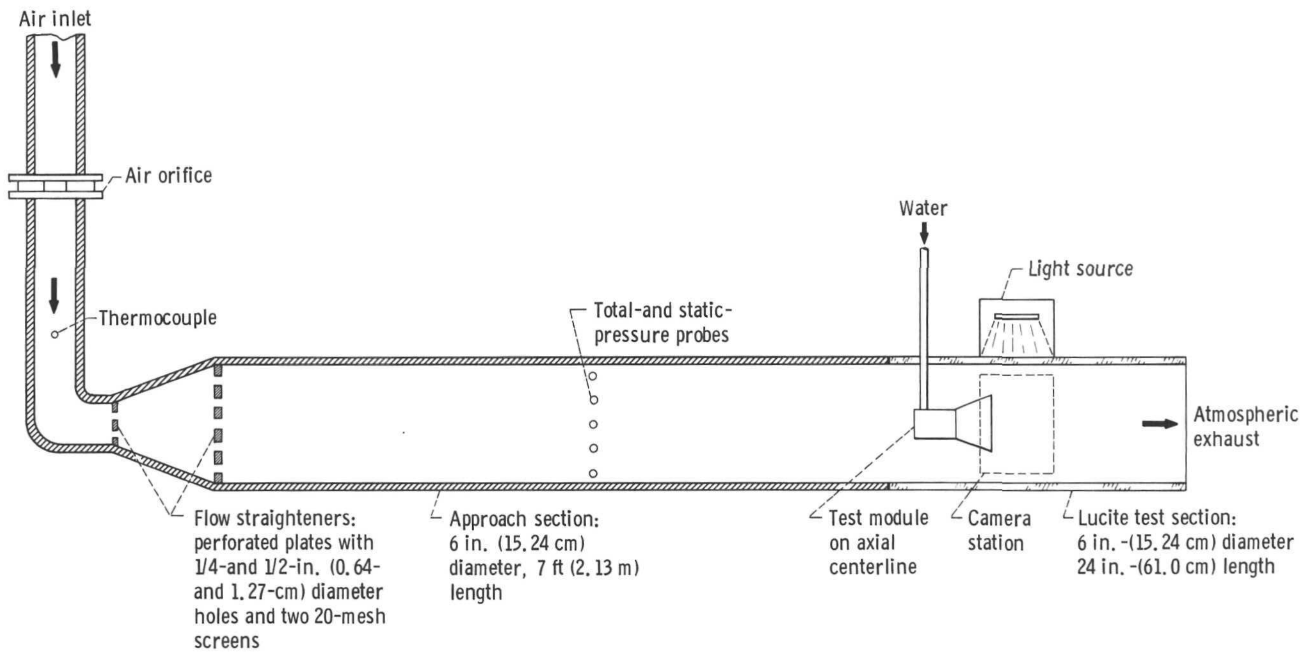


Figure 2. - Schematic diagram of cold-flow facility.

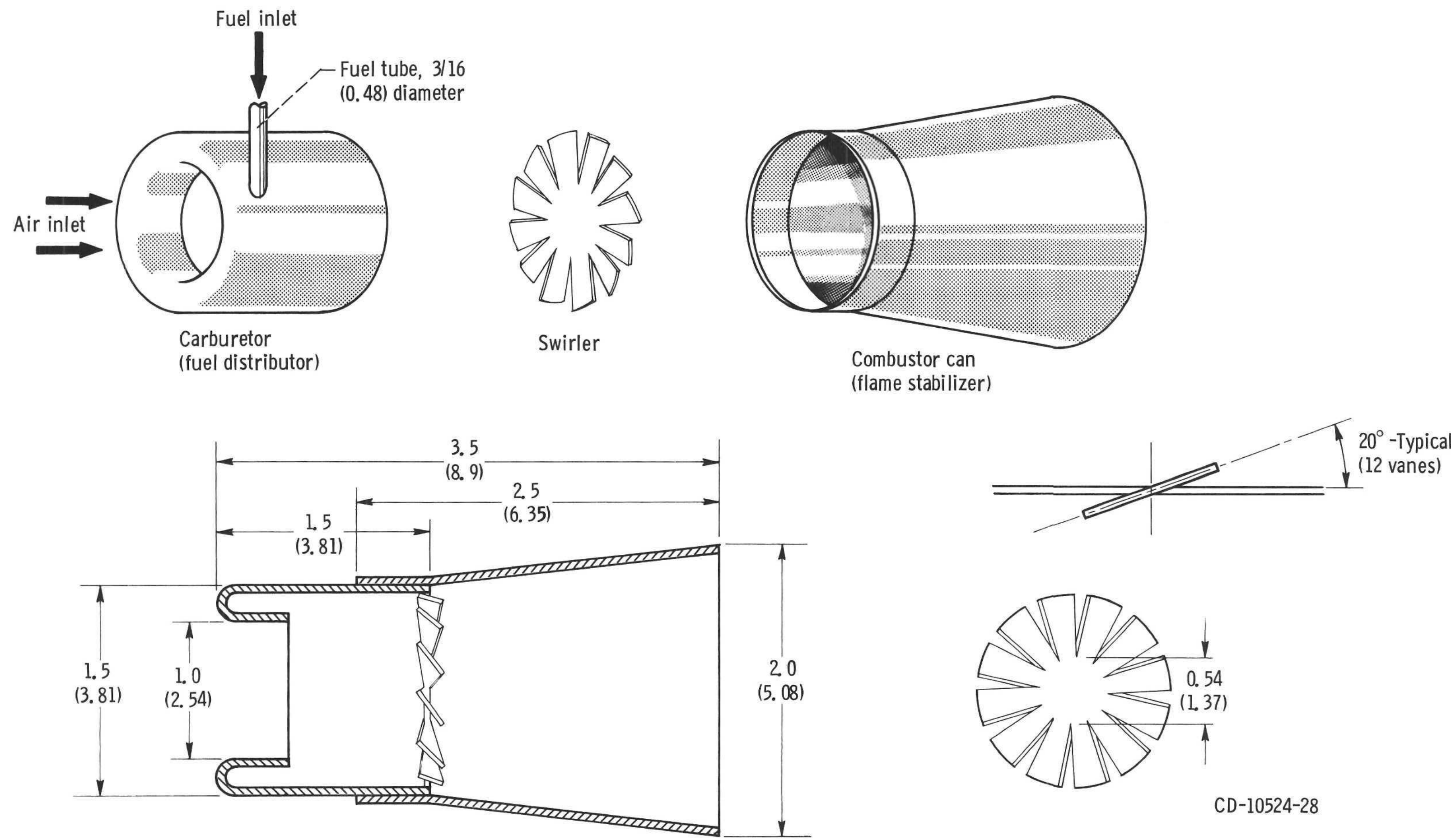


Figure 3. - Swirl-can combustor module used as a standard for comparison. Dimensions are in inches (cm).

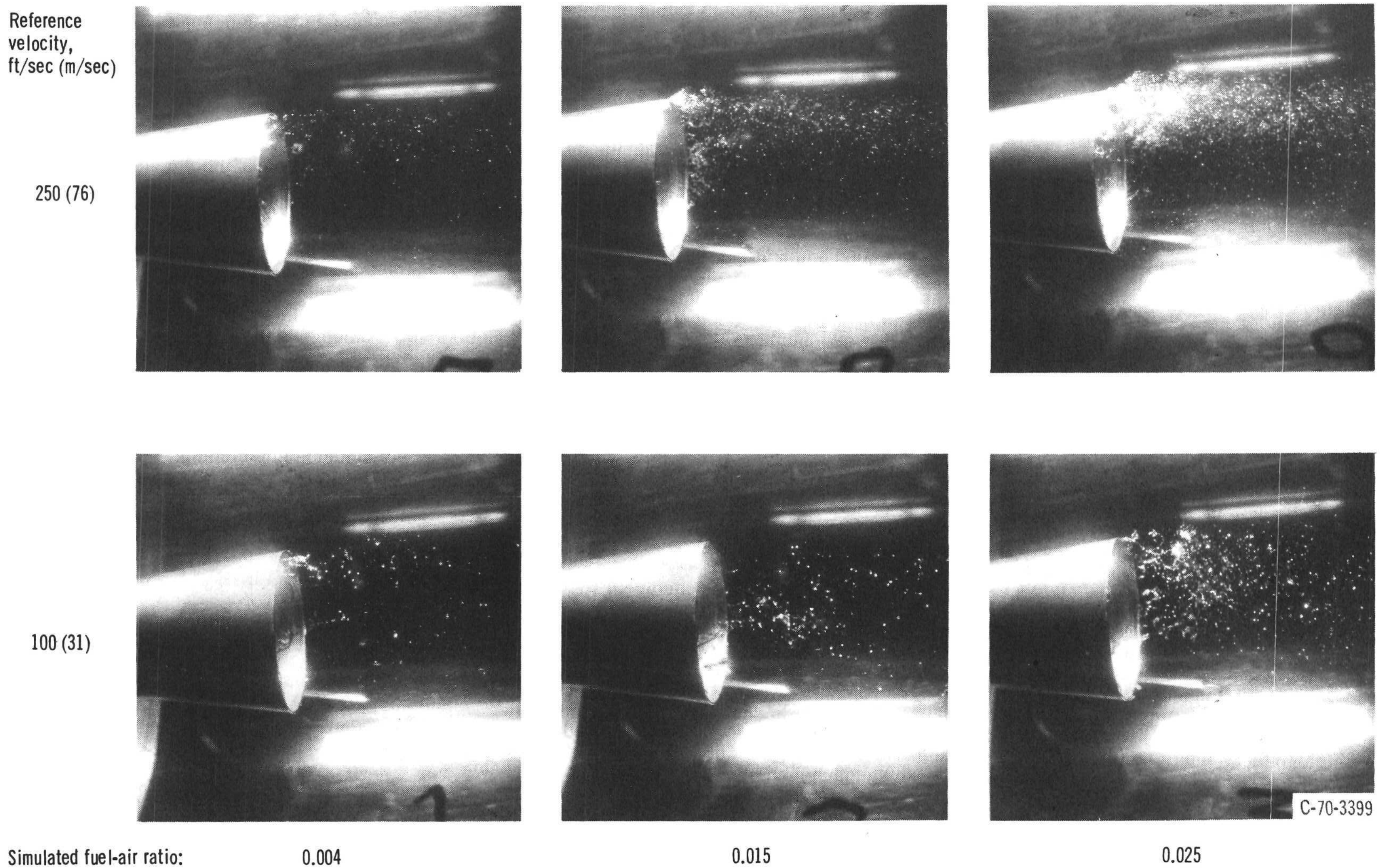
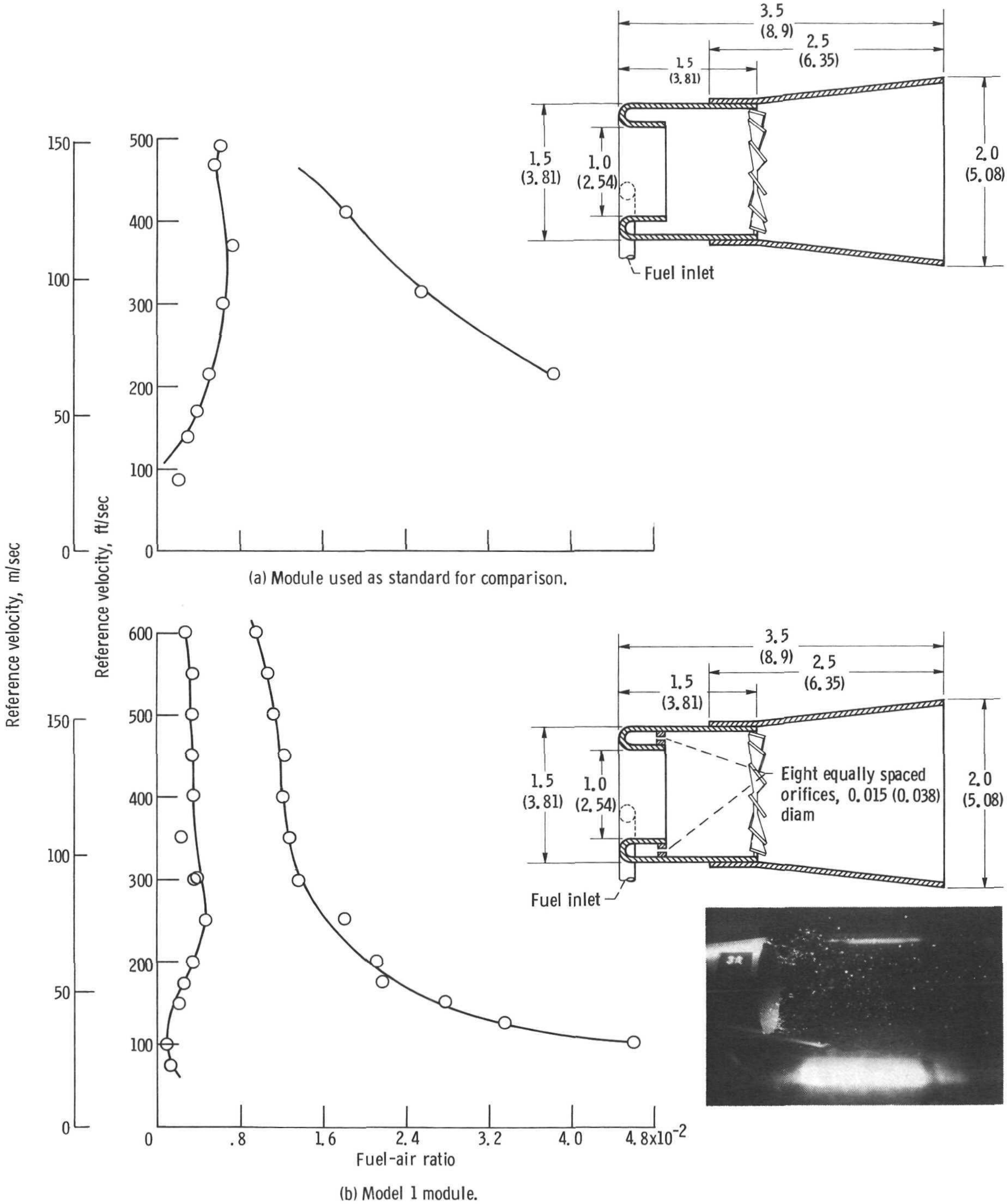


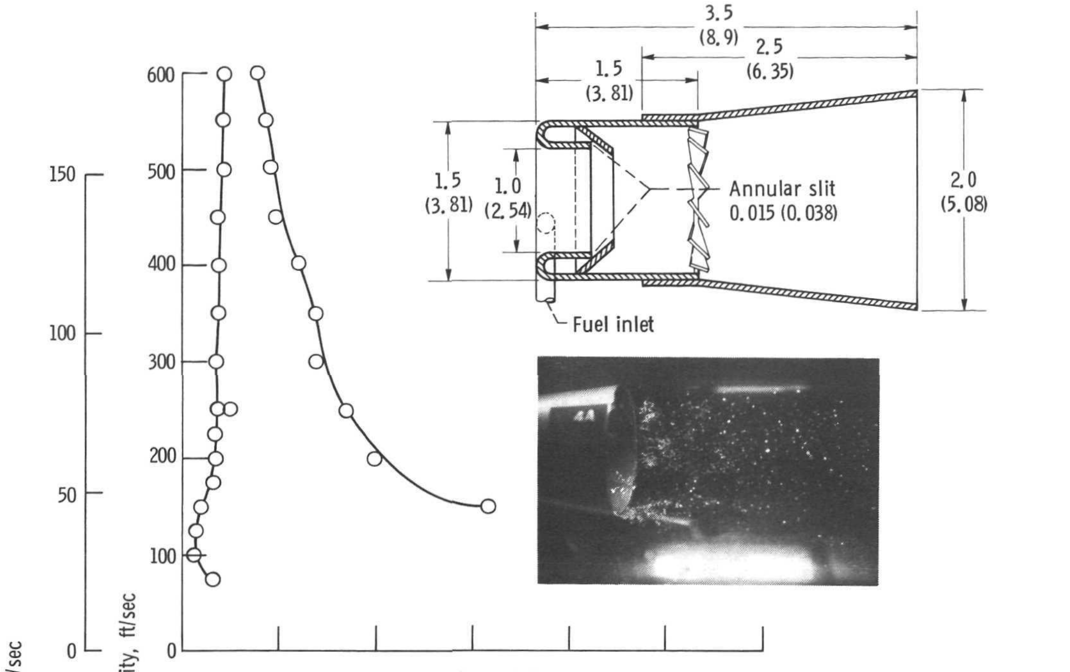
Figure 4. - Water spray patterns for the swirl-can combustor module used as a standard for comparison.



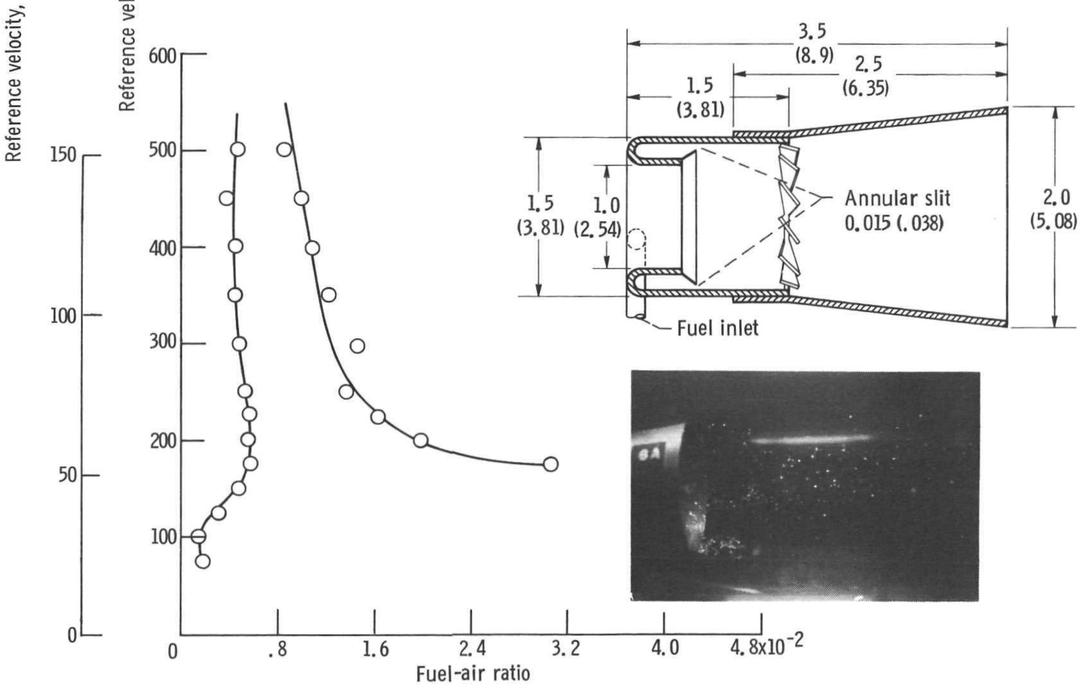
(a) Module used as standard for comparison.

(b) Model 1 module.

Figure 5. - Effect of fuel injection method on module combustion stability limits. Dimensions are in inches (cm). Reference velocity, 100 feet per second (30.5 m/sec); simulated fuel-air ratio, 0.015 (see photographs).



(c) Model 2 module.



(d) Model 3 module.

Figure 5. - Concluded.

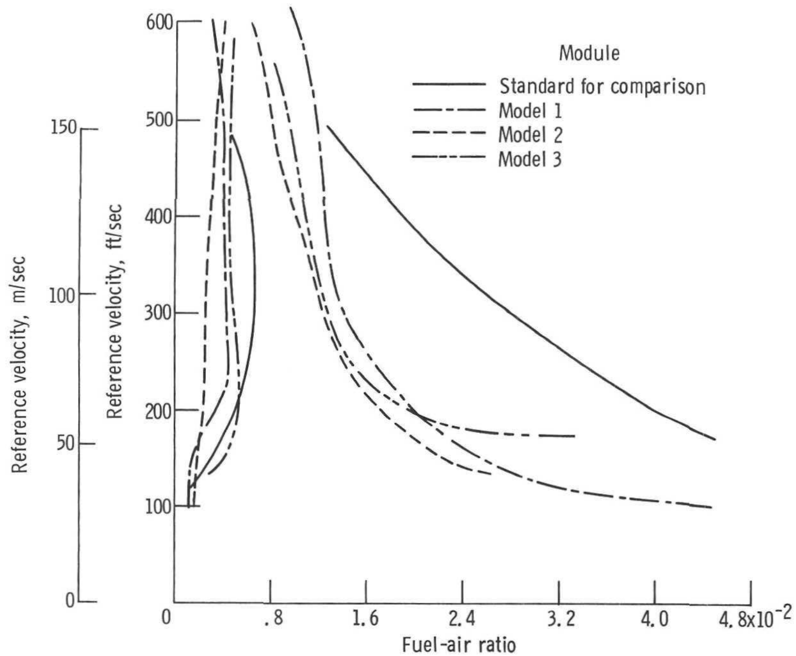


Figure 6. - Comparison of combustion stability limits for the four methods of fuel distribution.

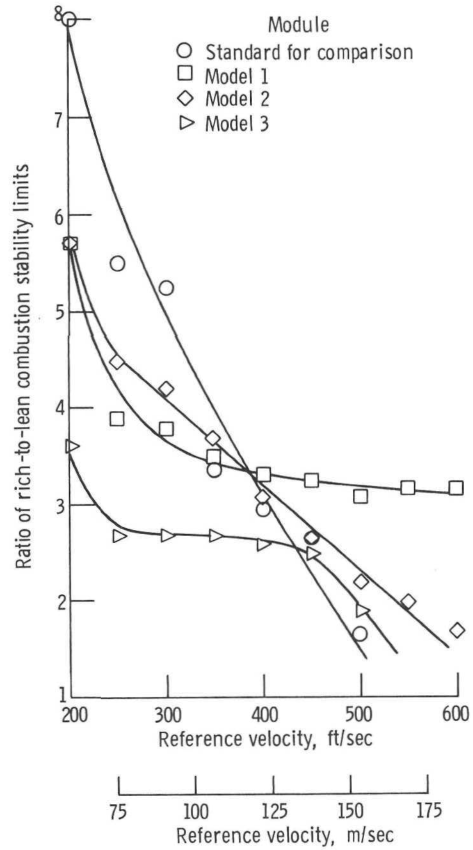


Figure 7. - Module performance comparison for four fuel-distribution methods; based on the ratio of rich-to-lean combustion stability limits.

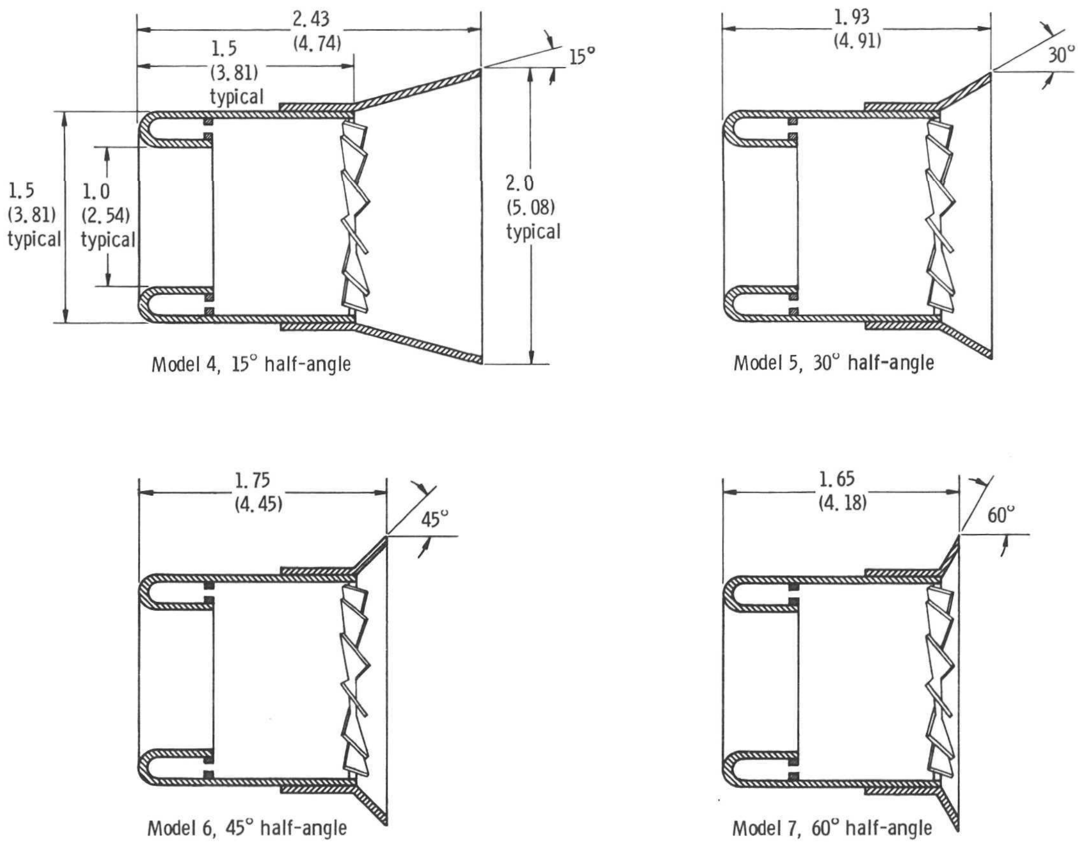


Figure 8. - Combustor modules with various flame-stabilizer half-angles. Dimensions are in inches (cm).

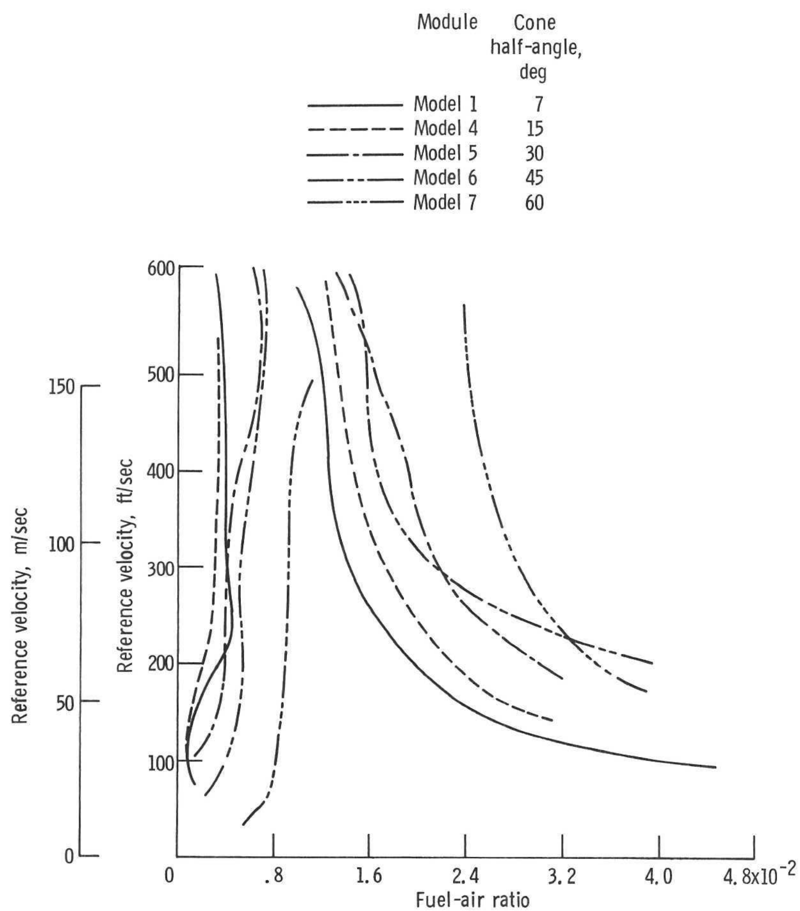


Figure 9. - Comparison of combustion stability-limit data for flame-stabilizer cone half-angles of 7° to 60°.

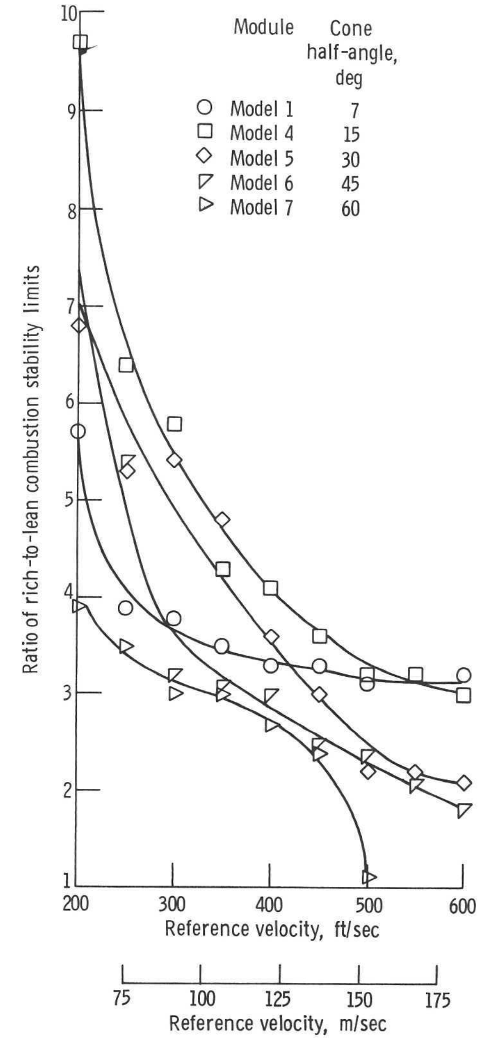


Figure 10. - Module performance comparison for cone half-angles of 7° to 60°; based on the ratio of rich-to-lean combustion stability limits.

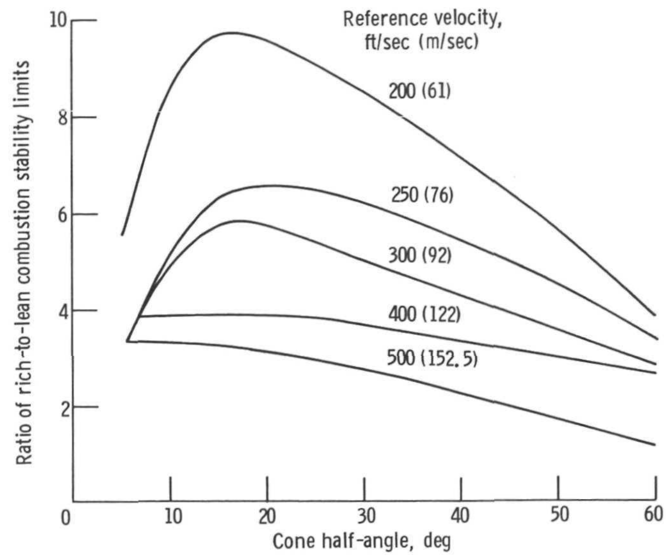


Figure 11. - Effect of cone half-angle of flame stabilizer on ratio of rich-to-lean combustion stability limits.

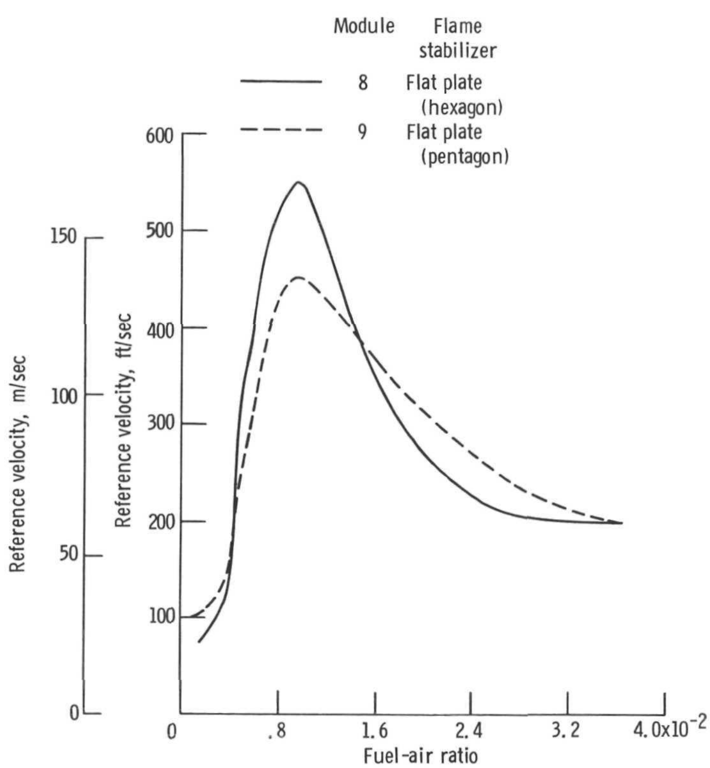


Figure 12. - Comparison of combustion stability-limit data for flat-plate flame stabilizers, with blocked area of approximately 40 percent for each module.

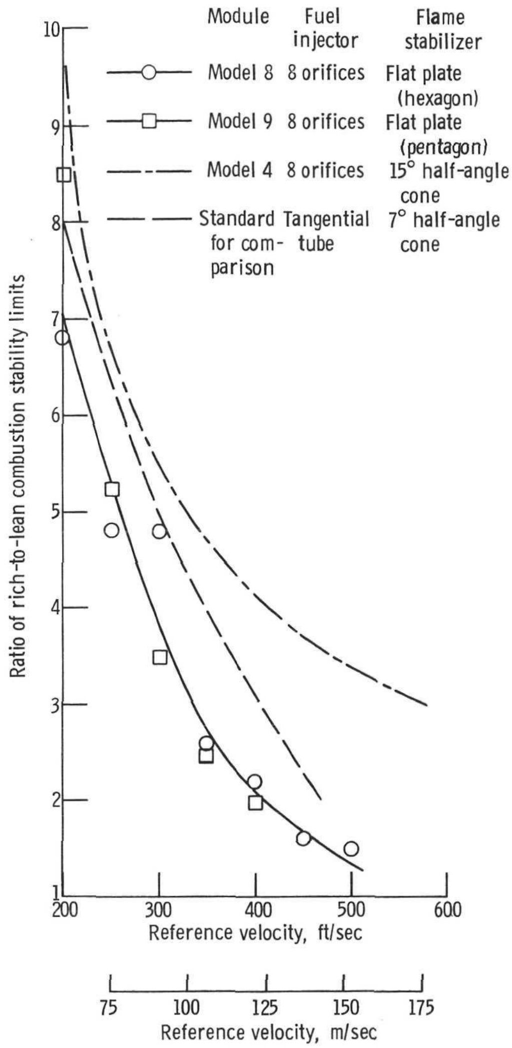


Figure 13. - Module performance comparison for flat-plate flame stabilizers and other modules; based on the ratio of rich-to-lean combustion stability limits.

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